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Mining Geology of the Fire Clay Coal

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Introduction

The Fire Clay (Hazard No. 4) coal is one of the leading producers in the Eastern Kentucky Coal Field, with more than 20 million short tons of annual production and 230 million short tons mined between 1976 and 1992, according to Kentucky Department of Mines and Minerals data. Regional thickness and resources of the coal are calculated in Greb and others (1999c) and Thacker and others (2000a, b).

Stratigraphically, the coal occurs in the middle part of the Hyden Formation of the Breathitt Group (Fig. 1), which was previously part of the Breathitt Formation (Chesnut, 1992). The coal occurs between the Upper Whitesburg and Fire Clay rider coals. Locally, each of these coals may almost merge with the Fire Clay coal, forming a zone.

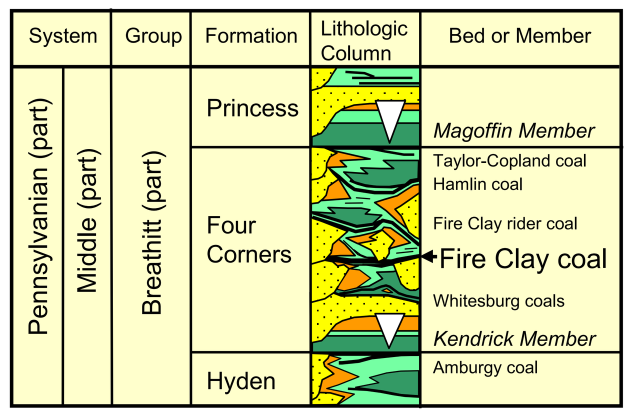

Figure 1. Stratigraphic position of the Fire Clay coal bed. See Figure 5 for explanation of symbols.

Flint Clay Parting (Jackrock)

The Fire Clay coal contains a regionally extensive flint-clay and shale parting, locally known as the jackrock. The distinctive hard, brown to gray flint clay has been the subject of numerous reports (Bohor and Triplehorn, 1981; Chesnut, 1983; Lyons and others, 1992). It contains sanidine phenocrysts, beta-quartz pseudomorphs, euhedral zircons, and iron-titanium, which indicates that it was deposited as a volcanic ash fall (Fig. 2). Samples of sanidines from the flint clay in eastern Kentucky and West Virginia have been radiometrically dated and indicate that the blanket of volcanic ash covered the initial accumulation of the Fire Clay coal (after it had been partially drowned) 311 million years ago, plus or minus 1 million years (Lyons and others, 1992).

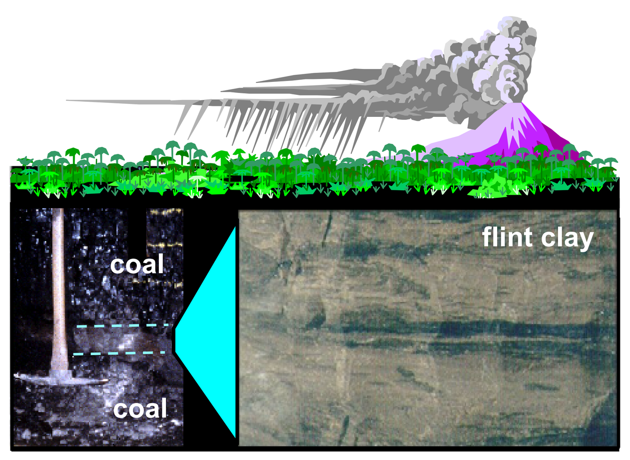

Figure 2. Illustration of volcanic ash fall and photograph of the flint-clay parting.

Multiple-Bench Architecture

The distinctive flint-clay parting in the Fire Clay coal divides the seam into two sub-units, called *benches*, above and below the parting (Fig. 3A–B). Regional thickness and quality analyses of the benches indicate that they have separate and distinctive trends (Eble and Grady, 1990; Eble and others, 1994, 1999; Greb and others, 1999a, b). The upper bench is the most persistent and has the lowest ash yields and sulfur contents overall. The lower bench is laterally restricted, varies in composition, and often has higher ash yields. In addition, local rider benches may merge with the top of the seam (Figs. 3B, 4). Rider benches generally have higher ash yields and sulfur contents. The seam at any one location may be a composite of these benches (Fig. 4). Analysis of the seam's *architecture*, which is the relative contribution of benches to the whole seam, can aid in meaningful projection of data for resource evaluation (Greb and others, 1999b; Thacker and others, 2000a).

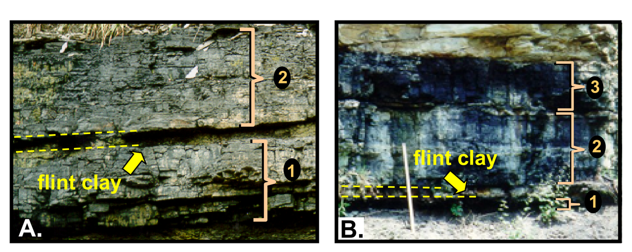

Figure 3. The flint clay in the Fire Clay coal may occur (A) within the coal, where it can be used to divide distinct benches of the coal (1 and 2), or (B) in or near the floor. Rider benches may also merge with the coal and contribute to seam thickness (3).

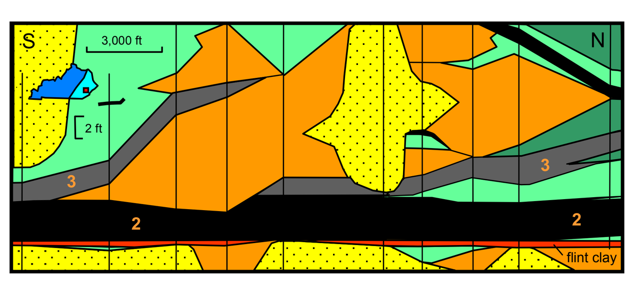

Figure 4. Lateral changes in coal-bench architecture (benches numbered as in Figure 3) in the Fire Clay coal in part of Perry County (after Greb and others, 1999a). Refer to Figure 5 for explanation of symbols.

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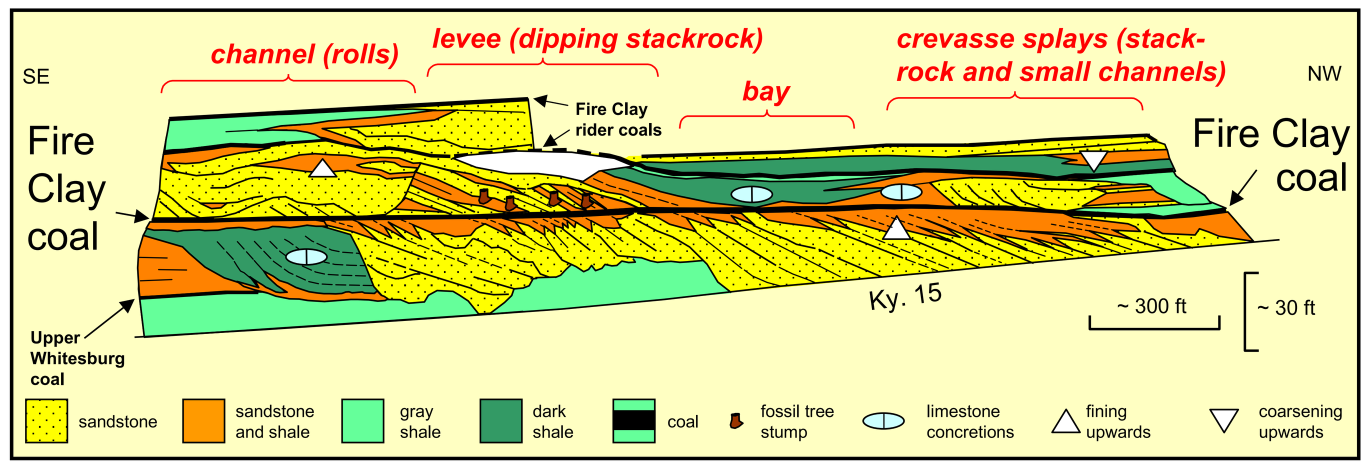

Figure 5. Lateral variation in roof rock above and below the Fire Clay coal exposed above old mine works near Hazard, Perry County, on Ky. 15. The environments in which the rocks in the interval between the Fire Clay and Fire Clay rider coals were deposited are shown in red.

Coal and Roof-Rock Variation

As with most eastern Kentucky coals, mine roofs above the Fire Clay coal are laterally variable. A typical example of the type of lateral variation in many Fire Clay mines is shown in Figure 5. Laterally, the roof changes from a sandstone (deposited in an ancient river), to inclined sandstones and shales (deposited on the levee adjacent to the channel), to dark shales (deposited in a bay, lagoon, and floodplain beyond the levee), to interbedded sandstones and shales (deposited in small flood deposits called crevasse splays). Several of the most common geologic obstacles encountered in these types of roof rocks and rock bedding are illustrated in this chart.

Regionally, roof lithology and coal thickness often vary along northeast–southwest and northwest–southeast trends (Fig. 6). These trends may define subtle growth faults that were active during deposition of the Fire Clay coal and roof strata (Fig. 7) (Weisenfluh and Ferm, 1991; Greb and others, 1999a, b).

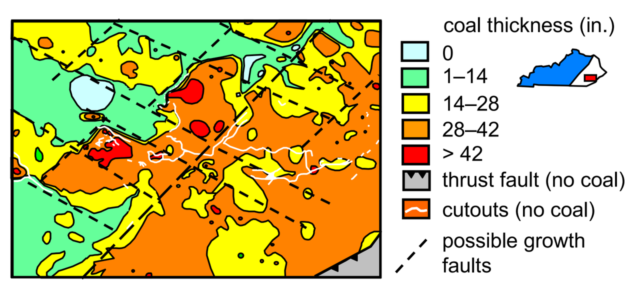

Figure 6. Coal thickness in parts of Knott, Leslie, Letcher, and Perry Counties, showing right-angle trends in distribution (after Greb and others, 1999b, Fig. 31).

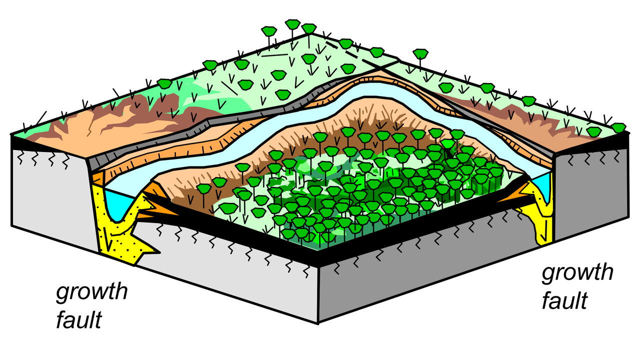

Figure 7. Synsedimentary growth faulting may cause rectangular distribution trends, merging coal benches, right-angle changes in cutout trends, and, in some areas, vertically stacked sandstones.

Sandstone Cutouts and Roof Rolls

Cutouts and roof rolls (bowing down of coal) beneath sandstones in the roofs of Fire Clay coal mines are relatively common (Figs. 8–9). Many are discontinuous along trend, and rise and fall in the roof. At least one trend, however, is continuous through parts of several counties (Fig. 10) (Greb and others, 1999a, b; Thacker and others, 2000b). This cutout has an overall east–west orientation, but makes several sharp, northeast–southwest and northwest–southeast bends that may be related to structural controls (Greb and others, 1999a, b). Notations on maps for mines along this trend indicate sharp cutouts, coals dipping in elevation toward the cutout, and "bad top." Roof falls along this trend are caused

Figure 8. Sharp cutout of the Fire Clay coal exposed along Ky. 80 near Martin.

Figure 9. Gradual thinning toward cutout of the Fire Clay coal exposed in a box cut near Hindman.

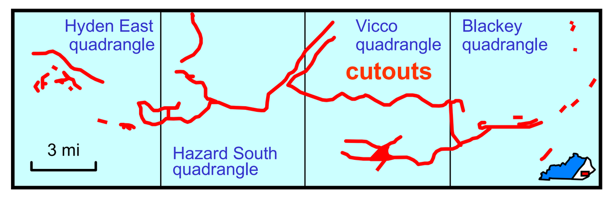

Figure 10. Cutouts of the Fire Clay coal in parts of Knott, Leslie, Letcher, and Perry Counties form a near-continuous belt.

by (1) slickensided shale or rotated bedding beneath pockets in the sandstone, or where sandstones cut lateral shale roofs, and (2) compactional slips along the roll or cutout.

Across most of the area in which the coal is mined, cutouts are sharp (Fig. 8), although the coal may gradually thin beneath overlying sandstones before being cut through (Fig. 9). Most cutouts in the main mining area of the Fire Clay coal are not associated with increased partings in the coal. In parts of Leslie County, however, and other areas on the margins of mining, increased partings and sulfur balls have been encountered lateral to cutouts.

Sandstone cutouts and rolls in Fire Clay mines were mostly deposited as ancient river channels (Fig. 11) and are similar to paleochannels discussed in the literature for other coals (Horne and others, 1978; McCabe and Pascoe, 1979; Moebs, 1981; Greb, 1991). Because they were deposited in channels, these types of sandstones and associated mining conditions tend to follow linear to slightly sinuous trends that can sometimes be projected in advance of mining.

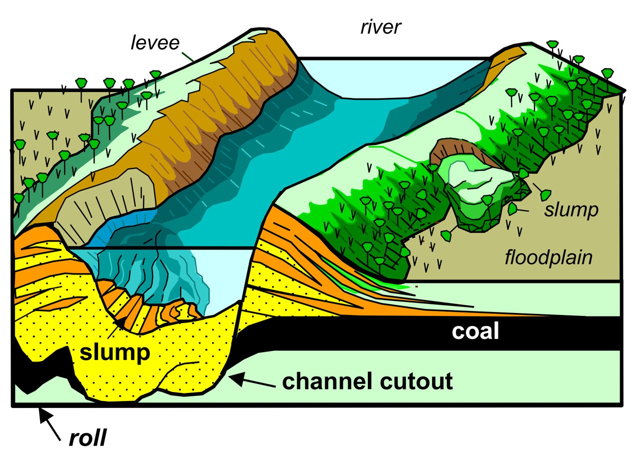

Figure 11. Many cutouts were formed when ancient river channels truncated underlying peats. In some cases, bank collapses along the channel margin created slumps.

Rotated-Bedding Roof Falls

Large falls along the margins of paleochannels, or beneath downcutting paleochannel sandstones, are often caused by slickensides and rotated bedding. Slickensides develop in shales when they are compacted beneath irregularities in overlying rock units, or where bedding has slid or been rotated from the horizontal plane. Rotated bedding in some Fire Clay mines appears to be caused by paleoslumps, which were formed from the slumping or failure of ancient channel margins into the channel (Figs. 11–12). Several paleoslumps have been noted along the continuous trend of cutouts in Leslie and Perry Counties. Figure 13 is a diagram based on in-mine measurements of paleoslumps within two cutouts of the Fire Clay coal. Some of the features associated with the paleoslumps are sudden increases in dip angle of beds along curved shear planes in the roof (Figs. 13–14), slickensided rotation surfaces (Figs. 13–14), near-vertical beds including coal (Figs. 13, 15), tightly folded bedding (Figs. 13, 16), and an island of relatively undisturbed coal between two paleoslumps (Fig. 13) (Andrews and others, 1994; Greb and Weisenfluh, 1996). Coal is thicker in the island area than in surrounding areas because slumping had torn a block of the original peat and thrust it upon itself (Fig. 13). The evidence for over-thickening caused by the local thrust of peat on peat at this location is that there are two flint clays, when normally there is only one flint-clay parting. The two partings came from the in-place peat (now coal) and the thrust peat (now coal) block.

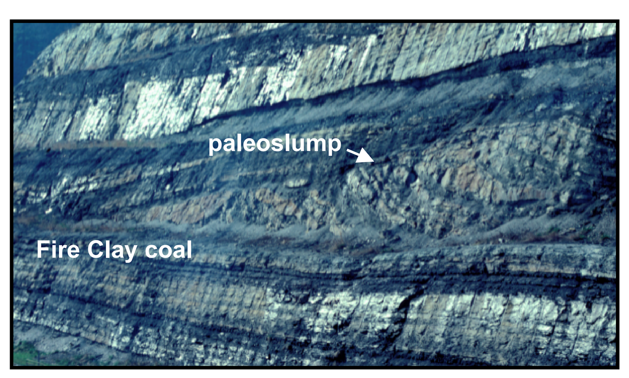

Figure 12. Rotated bedding in paleoslump above the Fire Clay coal along the Hal Rogers (Daniel Boone) Parkway, Leslie County.

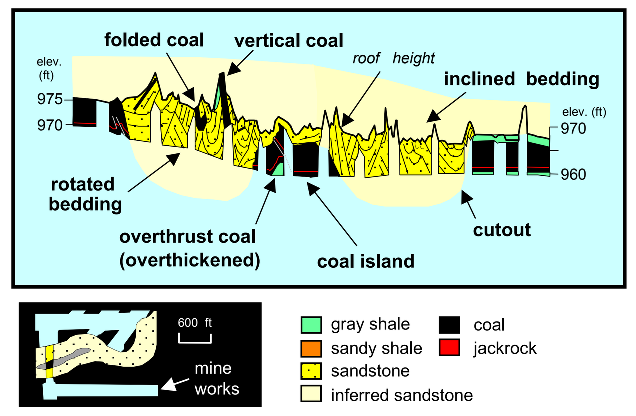

Figure 13. Cross section through two paleoslumps in a Fire Clay coal deep mine. An island of thick coal was preserved between the two cutouts, where a slice of the coal had been thrust upon itself. The map view shows the trend of the cutouts (yellow) and mine workings (blue) (after Greb and Weisenfluh, 1996, Fig. 8). Area shaded in light yellow is area of inferred sandstone.

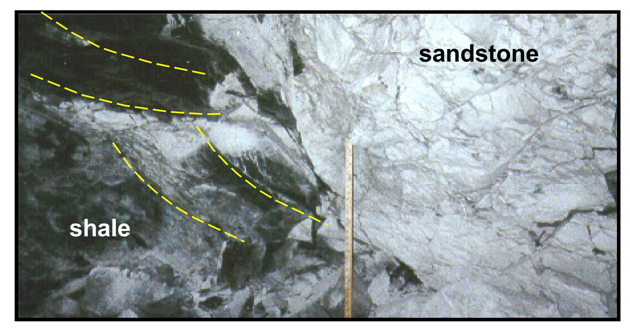

Figure 14. Shales beside rotated sandstone blocks contain numerous slickensided sheer planes (yellow dashed lines).

Figure 15. View upward into paleoslump roof showing near-vertical beds, slickensides, and jumbled, chaotic bedding.

Figure 16. Folding of roof strata toward toe of paleoslump.

Stackrock Roof Falls

Stackrock roofs are common in Fire Clay coal mines (Fig. 17). Stackrock consists of interbedded, thin-bedded rock. In some cases, horizontally interbedded rocks occur across broad areas. In others, stackrock dips at moderate angles within wedges of strata that become shaly in the direction of thinning and sandy in the direction of thickening. Sandstone bodies of varying widths commonly are lateral to stackrock, or truncate stackrock (Fig. 5). Falls are most common where sandstone beds are thin (less than 3 ft) and are interbedded with abundant, closely spaced shale or coaly laminae (Fig. 17). This is especially the case along the thinning margin of stackrock units where they are overlain by gray shale or coal riders (Moebs and Ellenberger, 1982; Hylbert, 1984; Greb, 1991; Weisenfluh and Ferm, 1991), or where stackrock is cut by fractures or hill seams. Stackrock falls are generally flat-topped with near-vertical sides along ribs. Fall height may be determined by the height of the first competent bed.

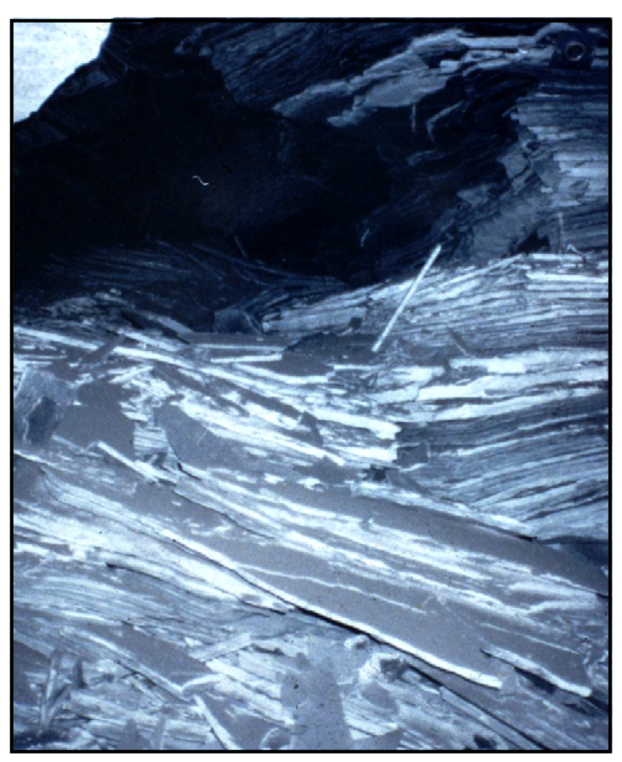

Figure 17. Stackrock roof fall in Fire Clay coal mine.

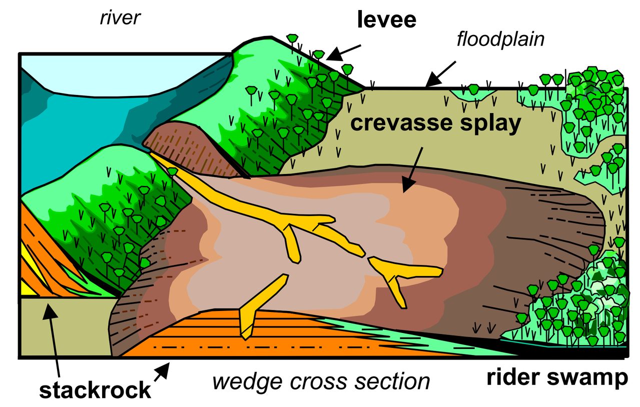

Figure 18. Stackrock sometimes formed when aprons of sediment flooded underlying peat swamps. Sometimes peats accumulated on the sediments and formed rider coals.

Stackrock in Fire Clay coal mines were mostly formed as levees and flood deposits along ancient paleochannels (Fig. 18). Dipping stackrock units along the margins of paleochannel cutouts were deposited as levees, and often contain fireclays or are capped by thin coal riders. Horizontally bedded stackrock units were often deposited in crevasse splays. Splays are a type of flood deposit that have lobate, fan-shaped geometries.Thin channels associated with splays are called crevasses, and often occur at right angles to larger, lateral paleochannels. These associations may be preserved in stackrock units above coals (Horne and others, 1978; Moebs and Ellenberger, 1982; Hylbert, 1984; Weisenfluh and Ferm, 1991).

Rider Coal Roof Falls

The Fire Clay rider bed may drop in elevation near the top of the Fire Clay coal (Fig. 19), forming a coal zone (Weisenfluh and Ferm, 1991; Thacker and others, 2000a). In several areas where this happens the coals are surface mined together (Fig. 20). In general, the two coals are not deep mined in the same vicinity because of their proximity and because in many cases, where one coal is thick, the other is thin (Thacker and others, 2000a, b).

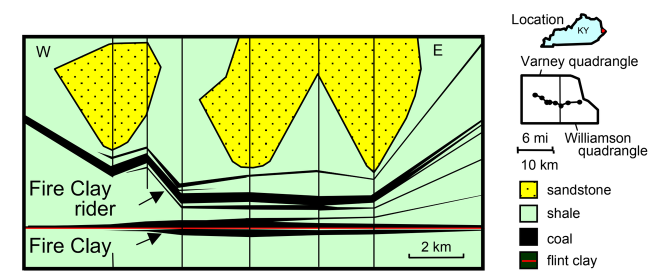

Figure 19. Cross section from part of Pike County, where the Fire Clay rider drops in elevation near the top of the Fire Clay coal bed.

Even where the Fire Clay rider does not drop in elevation toward the top of the Fire Clay, multiple, thin (less than 6 in.) coal riders may occur between the Fire Clay and Fire Clay rider beds. Some of these intervening rider coals cap laterally thinning stackrock intervals (Figs. 5, 19–20). As the stackrock interval thins laterally, the capping rider coal can drop in elevation toward the top of the coal. Roof falls are common where riders are within 10 ft of the top of the coal, especially where riders are underlain by slickensided and disrupted claystones (Weisenfluh and Ferm, 1991).

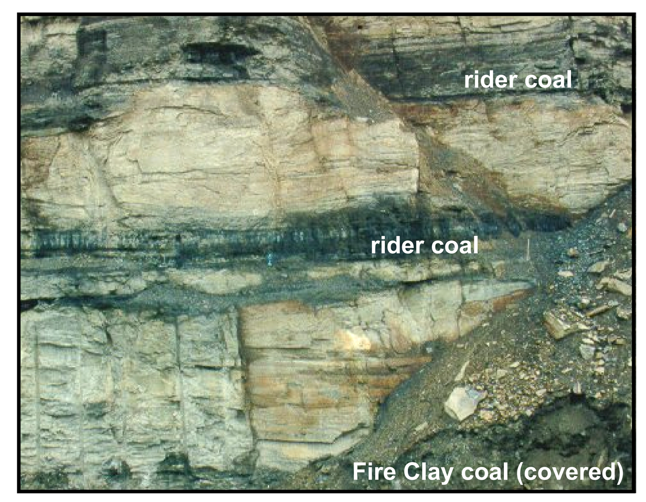

Figure 20. Rider coal beds near the top of the Fire Clay coal.

In some cases, rider coals may directly cap the Fire Clay coal, or merge with the Fire Clay coal, so that the rider is a bench of the mined coal. This merger can present a mining conundrum: the mined coal thickness is increased, but the rider benches generally have higher ash and sulfur values (Eble and others, 1994; Greb and others, 1999a).

Coal riders represent the accumulation of additional peat after burial of the main peat swamp. Where riders are in the immediate roof of underground mines, roof falls are possible because of poor bonding between thin coals and underclays, ancient rooting structures and slickensides in underlying fireclays that disrupt bedding, and shale-coal contacts that concentrate moisture; these contacts promote shale swelling and continued falls (Horne and others, 1978; Moebs and Ellenberger, 1982; Hylbert, 1984; Greb, 1991; Weisenfluh and Ferm, 1991).

Kettlebottoms

Another common condition in Fire Clay coal mines is shale roofs with kettlebottoms. Kettlebottoms are isolated, tubular blocks of sandstone or hard shale in mine roofs; they are fossil casts of tree stumps (Figs. 21–22A). From beneath, in mine roofs, they appear as circular rocks (Fig. 22B) or bulges. The outside rims of kettlebottoms are slickensided (Figs. 22C–D), so that they readily fall from mine roofs, and require supplemental support (Chase and Sames, 1983; Greb, 1991). In several Fire Clay and Fire Clay rider mines, large groups of kettlebottoms have been encountered. If one is encountered during mining, more are likely to occur.

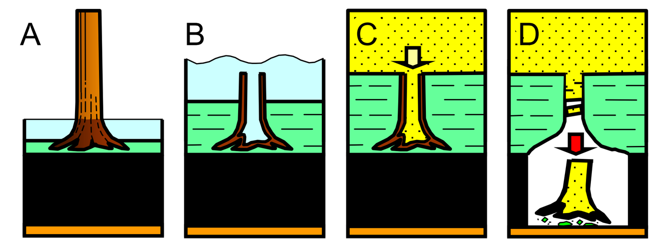

Figure 21. Kettlebottoms formed when tree stumps (A) were buried (B) and filled with sediment (C). Eons later, when the coal beneath is mined, they can fall out of the roof.

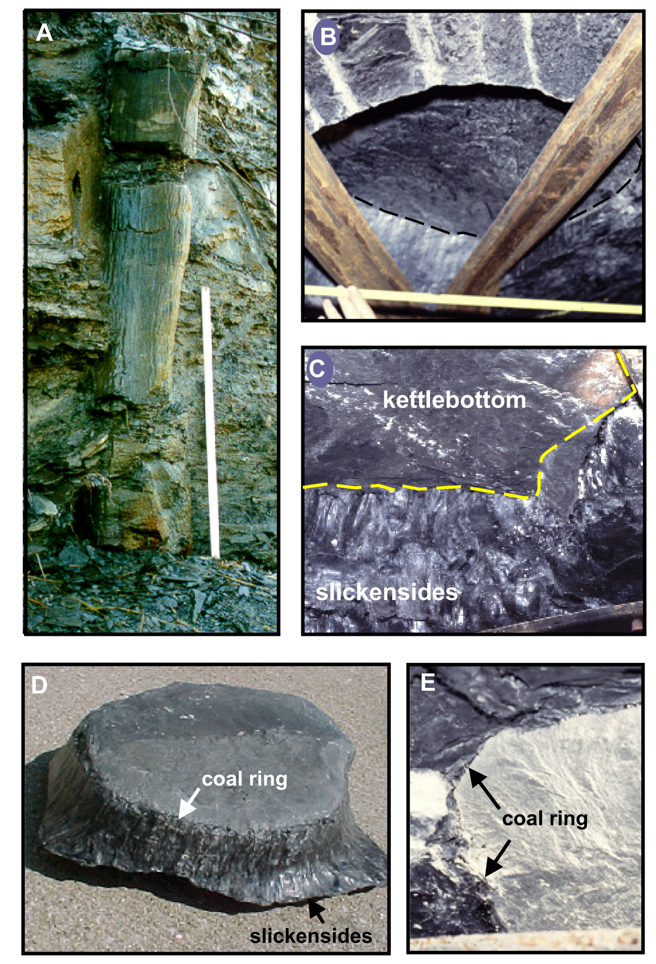

Figure 22. Kettlebottoms are locally common above the Fire Clay coal. (A) In outcrop, they can be seen as fossil tree stumps. (B–C) In a mine, only the circular cross section of the tree or root bundle is seen. Thin coal rings on the outside of the kettlebottoms, and the shale in contact with the kettlebottom, are often slickensided (C–E).

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